The views expressed herein are the personal views of the authors and are not necessarily the official views of the Department of Defense nor the Naval Sea Systems Command.

THE AUTHORS

David A. Breslin P.E. *is employed by the Naval Sea Systems Command (NAVSEA) in the CFC & Halon Elimination Program Office and is the Vice Chairman for Technology of the ASNE Committee on Environmental Engineering. He received a master of science in aerospace & ocean engineering from Virginia Tech in 1991, a master of engineering administration in industrial & systems engineering from Virginia Tech in 1991, and a bachelor of engineering in mechanical engineering from Stevens Institute in 1985. Since 1993, he has been the program manager of NAVSEA's CFC & Halon Elimination Program. He received a Stratospheric Ozone Protection Award in 1995 from the EPA in recognition of "exceptional contributions to global environmental protection".*

Gregory P. Brunner *is employed by the Naval Sea Systems Command (NAVSEA) in the CFC & Halon Elimination Program Office. He graduated with master of mechanical engineering and bachelor of mechanical engineering degrees from the Catholic University of America. Since 1993, he has been the program manager for the R&D efforts in the NAVSEA CFC & Halon Elimination Program Office. Program efforts have resulted in the development of new refrigerants for backfit into existing shipboard air conditioning and refrigeration systems, and for the development of new-design shipboard air-conditioning and refrigeration equipment which use non-ozone-depleting alternative refrigerants.*

Joseph C. Thill *is employed by the Naval Sea Systems Command (NAVSEA) in the CFC & Halon Elimination Program Office. He received a AA in Business Administration from Saint Leo College. He served in the U.S. Navy as a technical manager for removal, installation, testing and operating nuclear systems on submarines. He is currently the program manager of the Navy's CFC-12 conversion program responsible for converting the Fleet's 1,050 CFC-12 AC&R plants to ozone-friendly HFC-134a by 2001. Prior to this assignment, he was assigned to the Submarine HVAC and Life Support Branch where he was the life cycle manager for submarine life support equipment.*

Gregory S. Toms P.E. *is employed by the Naval Sea Systems Command (NAVSEA) in the CFC & Halon Elimination Program Office. He received a master of science degree in mechanical engineering from the University of Maryland and a B.S. degree in mechanical engineering from West Virginia University. He is currently the program manager responsible for the conversion of shipboard centrifugal compressor air conditioning plants from refrigerant CFC-114 to ozone-friendly HFC-236fa. Prior to this assignment, he was employed at the Naval Surface Warfare Center, Carderock Division, Annapolis Detachment (formerly David Taylor Research Center) where he worked on the development of advanced centrifugal compressor air conditioning plants for shipboard applications. He is licensed as a registered Professional Engineer in the state of Texas.*

ABSTRACT

The domestic production of Class I Ozone-Depleting Substances (ODSs) has permanently ceased and the abundant supplies of a number of inexpensive refrigerants, fire-fighting agents, and solvents, once taken for granted, are now part of history. The Navy's original strategy of conserving ODSs, converting systems and processes where feasible, relying on stockpiles where necessary, and developing "ozone-friendly" equipment for new-design surface ships and submarines is succeeding. The purpose of this paper is to document the Navy's efforts to date relative to combating the threat to uninterrupted Fleet operations posed by the cessation of ODS production.

BACKGROUND AND REQUIREMENTS

Various synthetic chemicals, commonly known as Ozone-Depleting Substances (ODSs), have been implicated in the destruction of the Earth's protective stratospheric ozone layer.[1] As a result of international treaty and U.S. legislation, the domestic production of halons permanently ceased on December 31, 1993, and the domestic production of chlorofluorocarbons (CFCs) permanently ceased on December 31, 1995.[2] Many of these ODSs, however, are refrigerants, solvents, and fire-fighting agents that have been playing critical roles in daily ship operations.

In advance of the impending production cessation, the 1993 Department of Defense Authorization Act placed certain restrictions on contracts and made it more difficult to buy ODSs for maintenance and repair and ODS-based systems for new construction.[3] In addition, the Chief of

Naval Operations required the reduction of the use of ODSs to the "lowest achievable level"[4] and, even more specifically, the Navy has at times directed that new-construction ships, such as the Amphibious Assault Ship (LPD 17), be built without CFCs or Halons.[5] These and a host of other requirements helped to create and cement the Navy's overall strategy addressing how to prevent ODS production cessation from affecting current and future Fleet operations.

Well prior to production cessation, it was realized that the Navy had continuing mission-critical requirements for a number of ODSs for the suppression of shipboard fires; the cooling of electronic & weapon systems, medical & food storage, and inhabited spaces; and the cleaning of critical oxygen systems. Therefore, production cessation posed a substantial threat to the operation of existing shipboard systems as well as future shipbuilding programs. In order to prevent production cessation from impacting current and future Fleet operations, the Navy established an aggressive program designed to conserve existing supplies of ODSs, convert systems where technically and economically feasible, and establish a mission-critical reserve that would support the Fleet until individual systems were converted or retired from service. In addition, the Navy invested in developing next-generation, ozone-friendly, shipboard systems designed for new-construction programs.[6]

MISSION-CRITICAL RESERVE

Since the conversion or replacement of existing ODS-based systems prior to production cessation was not feasible and the availability of ODSs subsequent to production cessation was uncertain, the establishment of a mission-critical reserve (or stockpile) designed to support mission-critical applications became a necessary component to the Navy's overall strategy. The Navy's reserve for shipboard applications, which is designed to support mission-critical applications between production cessation and the point at which the last system is converted or retired from service, includes refrigerants CFC-11, CFC-12, and CFC-114; solvent CFC-113; and fire-fighting agents Halon 1211 and Halon 1301.[7]

The size of the Navy's reserve, which was defined in 1994, was based on assumed per-unit consumption rates, force-structure projections, and expected equipment conversion, replacement, and retirement schedules, as applicable. The longevity of each component of the reserve is therefore dependent on each of these variables. With respect to Halon 1301, it is currently believed that the reserve will be supporting the Fleet until *circa* 2050.[8]

Since the size of the reserve is finite and cannot be augmented in the future, a formal system has been established to closely monitor the draw-down of the reserve and help guard against premature depletion. As the Navy's force structure, conversion budgets, and consumption rates continue to change, the expected longevity of each component of the reserve will continue to change as well.[9] Thus far, all indicators show that the reserve is sufficient to meet all anticipated requirements.[10]

EXISTING CFC-11 AIR-CONDITIONING SYSTEMS

The Navy currently operates approximately thirty chilled-water, air-conditioning plants that use refrigerant CFC-11 on older surface ships.[11] Due to the age and limited number of these plants, the Navy did not invest in developing conversion packages for these plants and, therefore, these plants will rely on the Navy's reserve of CFC-11 until they are replaced with modern systems or the ships they service retire early in the next century.[12]

BACKFIT OF EXISTING CFC-12 AIR CONDITIONING AND REFRIGERATION SYSTEMS

The Navy has approximately 350 shipboard chilled-water air-conditioning plants and 700 shipboard refrigeration plants that were originally designed to operate using CFC-12 refrigerant. These plants incorporate reciprocating compressor designs, and have a history of poor reliability and high maintenance. Hydrofluorocarbon (HFC) -134a has been selected as the backfit replacement refrigerant for these plants, and fleet conversions have been underway since 1992. HFC-134a is non-flammable, has low toxicity, and has an ozone depletion potential (ODP) of zero. HFC-134a is being marketed throughout the air-conditioning and refrigeration industry as an alternative to CFC-12.

HFC-134a Investigations - Air Conditioning Plants [13]:

HFC-134a was selected as the backfit replacement for CFC-12 based upon its comparable physical and thermodynamic properties. Table 1 provides a comparison of CFC-12 and HFC-134a for an ideal (100% efficient) air-conditioning plant operating cycle with a 40^{o}F refrigerant evaporating temperature and a 100^{o}F refrigerant condensing temperature. Table 1 shows that HFC-134a has operating pressures similar to those of CFC-12, and requires the same approximate compressor displacement (flow rate) for a given cooling capacity.

Since HFC-134a is immiscible with the mineral oils traditionally used with CFC-12, an alternative compressor lubricant is required. Polyol ester (POE) lubricants have been identified by the air-conditioning and refrigeration industry as the lubricants of choice for use with HFC-134a and other HFC refrigerants. The Navy has performed extensive investigations with HFC-134a and POE lubricants in shipboard reciprocating compressor air-conditioning plants.

Table 1. HFC-134a and CFC-12 Ideal Air-Conditioning Cycle Comparison.

REFRIGERANT DESIGNATION	CFC-12	HFC-134a
Chemical Formula	CCl_2F_2	$C_2H_2F_4$
Evaporator Pressure (psia)	51.67	48.90
Condenser Pressure (psia)	131.86	139.00
Compressor Flow Rate (ft^3/min/ton)	3.07	2.99
Power (kW/ton)	0.51	0.51
Ozone Depletion Potential (ODP)	1.0	0
Global Warming Potential (GWP)	2.1	0.3

Notes:
(1) Data based on 40°F evaporating and 100°F condensing temperatures, with 100% efficient compressor and motor.
(2) ODP and GWP are relative to CFC-11 having a value of 1.0.

NAVSEA funded laboratory investigations of HFC-134a in shipboard-type 25-ton and 80-ton CFC-12 air-conditioning plants at Naval Surface Warfare Center, Carderock Division (NSWCCD), Annapolis Detachment, during the 1990-1994 time frame, Figures 1 and 2. These laboratory investigations revealed a 1-5% increase in cooling capacity with little or no increase (0-2%) in compressor motor power consumption, indicating that existing CFC-12 air-conditioning plant compressors and motors will have adequate capacity when converted to HFC-134a. Long term operational investigations were performed which demonstrated the suitability of the HFC-134a and POE lubricant fluid combination.

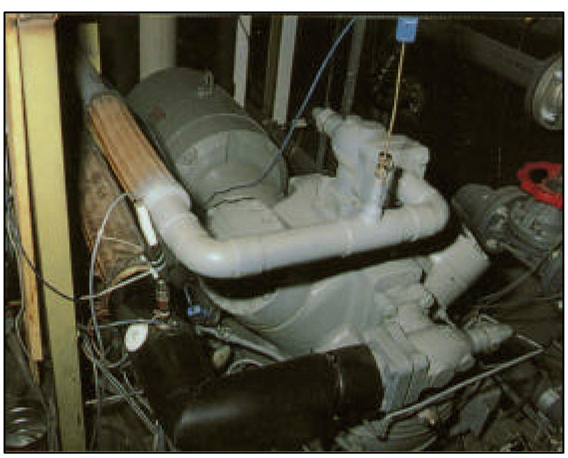

Figure 1. Shipboard-Type 25-Ton CFC-12 Air-Conditioning Plant.

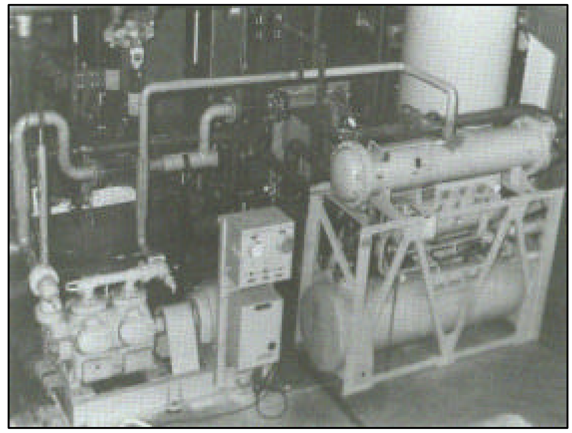

Figure 2. Shipboard-Type 80-Ton CFC-12 Air-Conditioning Plant.

The conversion procedures developed during these investigations are straightforward, and include a series of oil changes to remove residual mineral oil prior to conversion to HFC-134a. While the plant is still charged with CFC-12, the compressor mineral oil is drained and replaced with a POE lubricant. The plant is then operated under full load conditions for approximately two hours, and an oil sample is taken from the compressor for analysis of residual mineral oil. If the residual mineral oil content has been reduced to an acceptable level, the oil flushing is complete and the system is ready for the removal of CFC-12 and the installation of HFC-134a conversion hardware. Otherwise, the POE lubricant in the compressor is changed and the process continues until an acceptable residual mineral oil level is obtained.

In addition to HFC-134a and POE lubricant, other conversion items include replacing the activated alumina dehydrator cartridges with molecular sieve desiccant cartridges, an HFC-134a leak detector, and hardware modifications previously demonstrated to improve the reliability of the shipboard reciprocating compressor air-conditioning plants.

HFC-134a Investigations - Refrigeration Plants [14,15]:

HFC-134a was also selected as the backfit replacement for CFC-12 in Navy ship stores and cargo refrigeration plants. Table 2 provides a comparison of HFC-134a and CFC-12 for an ideal (100% efficient) refrigeration plant operating cycle with a -20°F refrigerant evaporating temperature and a 105°F refrigerant condensing temperature.

Table 2. HFC-134a and CFC-12 Ideal Refrigeration Cycle Comparison.

REFRIGERANT DESIGNATION	CFC-12	HFC-134a
Chemical Formula	CCl_2F_2	$C_2H_2F_4$
Evaporator Pressure (psia)	15.3	12.9
Condenser Pressure (psia)	141.2	149.60
Compressor Pressure Ratio	9.23	11.60
Compressor Flow Rate (ft^3/min/ton)	11.42	12.94
Power (kW/ton)	1.39	1.45
Ozone Depletion Potential (ODP)	1.0	0
Global Warming Potential (GWP)	2.1	0.3

Notes:
(1) Data based on -20°F evaporating and 105°F condensing temperatures, with 100% efficient compressor and motor.
(2) ODP and GWP are relative to CFC-11 having a value of 1.0.

Table 2 shows that HFC-134a requires an approximately 13% larger compressor to obtain the same cooling capacity as CFC-12 for the ideal cycle. This implies that if the same refrigeration compressor is used, a loss in cooling capacity of about 13% is predicted to occur when converting from CFC-12 to HFC-134a. The conversion loss can actually be expected to be greater since the compressor pressure ratio increases from 9.23 to 11.60, which reduces the compressor volumetric efficiency as more internal compressor leakage occurs with higher pressure ratios.

NAVSEA funded laboratory investigations of HFC-134a in CFC-12 refrigeration equipment at NSWCCD Philadelphia during the 1991-1995 time frame. Initial tests were conducted on a land-based 1.33-ton CFC-12 refrigeration plant that simulated a shipboard-type plant, Figure 3. The test results revealed a loss in cooling capacity of approximately 23% when converting from CFC-12 to HFC-134a. Testing also showed that this loss in cooling capacity could be recovered by increasing the compressor displacement by a corresponding amount.

Land-based tests at NSWCCD Philadelphia also demonstrated the need for an oil cooler in Navy refrigeration plant compressors. A refrigerant-cooled oil cooler design was selected, since chilled water is not readily available in most machinery spaces where shipboard refrigeration plants are installed. The loss in cooling capacity resulting from the installation of a refrigerant-cooled oil cooler was measured to be approximately 12%. Thus, for the CFC-12 refrigeration plant converted to HFC-134a with an oil cooler at NSWCCD Philadelphia, the total conversion losses were approximately 35%.

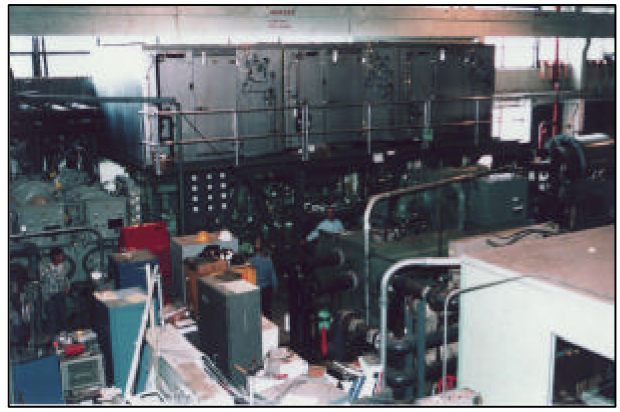

Figure 3. CFC-12 Refrigeration Plant Test Facility.

NAVSEA has examined all fleet refrigeration plant designs that are planned for conversion to HFC-134a, to determine whether there is adequate cooling capacity to meet the refrigeration loads with an estimated 35% loss in cooling capacity. Approximately 60% of the fleet refrigeration plants have adequate reserve capacity, a compressor speed increase will help recover the capacity loss in about 20% of the plants, while the remaining plants will require installation of a larger compressor to provide adequate cooling capacity.

The conversion procedures developed for Navy CFC-12 refrigeration plants are similar to those developed for Navy CFC-12 air conditioning plants. The plant is first operated using CFC-12 with a series of POE lubricant changes to reduce the residual mineral oil content to an acceptable level. After recovery of the CFC-12 refrigerant charge, HFC-134a conversion hardware is installed. Refrigeration plant conversion items include HFC-134a, POE lubricant, a compressor oil cooler, new power assemblies for thermal expansion valves, new molecular sieve desiccant dehydrator cartridges, an HFC-134a leak detector, and other hardware modifications to improve the reliability of the converted systems.

Fleet HFC-134a Conversion Program:

Test shipboard HFC-134a conversions were performed on the CFC-12 air conditioning and refrigeration plants onboard USS DeWert (FFG-45), and USS Mount Hood (AE-29) during the 1992-1994 time frame. The USS DeWert, Figure 4, was the Navy's first "CFC-12 Free" ship from an air-conditioning plant and ship stores refrigeration plant perspective (excluding unitary equipment). Following the successful completion of these shipboard demonstrations, fleet-wide CFC-12 air conditioning plant conversions began in early FY94, and fleet-wide CFC-12 refrigeration plant conversions began in mid-FY94.

Figure 4. USS DeWert (FFG-45), The Navy's First "CFC-12 Free" Air-Conditioning and Refrigeration Plant Ship.

Now well into the conversion program, the CFC Elimination Team (NAVSEA, NSWCCD, Fleet Technical Supports Centers, and contractor Alteration Installation Teams) has converted 409 of the approximately 1,000 shipboard air-conditioning and refrigeration plants in the fleet (over 40%) as of August 1997. The conversions have been performed on over 100 ships, of which 99 are "CFC-12 Free" (except for unitary equipment). The net result is the removal of approximately 50 tons of ozone-depleting CFC-12. Sixteen ship classes have had plants converted, with three classes completed: ARS-50, CG-47 and DDG-993.

As part of the CFC Conversion Plan, a pre-inspection is conducted approximately three to six months prior to the conversion of the plants. The inspection findings are forwarded to the ship, port engineers and Type Commander for action. The inspection discrepancies should be corrected prior to the start of the conversion. The first task of the conversion alteration installation team (AIT) is to determine if the inspection discrepancies have been corrected. The conversion AIT is authorized to correct only those repairs that are within the scope of the conversion and those items discovered during system testing and operation.[16]

The HFC-134a refrigerant system operation and maintenance remain very similar to that of CFC-12/mineral oil refrigeration systems. One significant difference is that HFC-134a refrigerant and POE lubricant are more active as cleansing agents than CFC-12 refrigerant and mineral oil. Consequently, the HFC-134a/POE combination dissolves and dislodges particles that had previously deposited and accumulated on piping walls during CFC-12/mineral oil operation. Dislodging these contaminants (carbonized mineral oil, iron, copper and aluminum oxidation, etc.) will degrade the operation of the system components if not controlled.

Because of the cleansing action of the HFC-134a/POE combination, interim preventive maintenance has been established to assist the refrigeration technician during the system cleansing period. It could take three to six months following the conversion for HFC-134a/POE lubricant to purge the system of particulate matter, depending on the degree of system pre-conversion contamination.

The components requiring the most attention are the liquid-line dehydrator, liquid-line strainer, thermal-expansion valve (TXV), and compressor. These components tend to trap the loose particulate matter causing temperature fluctuation, erratic system operation, loss of capacity, and can contaminate the POE lubricant. To protect these components felt pads and socks are temporarily installed in the suction side of the compressor, liquid line dehydrator and the liquid line strainer to collect the loose particulate matter. If this particulate matter contaminates the lubricant, compressor wear can be accelerated resulting in significant reduction in compressor capacity and reliability.

HFC-134a refrigeration systems operate in a deeper vacuum on the suction side than a CFC-12 refrigeration system to achieve the designed storage box temperatures. This deeper vacuum can allow air and moisture to enter the system from any low side leaks. Air and moisture will also enter the system when maintenance is being performed. Unlike CFC-12 refrigeration systems that used mineral oil, POE lubricant is extremely hygroscopic. As in CFC-12 refrigeration systems, but at a much higher rate, moisture will promote acid development within the system and may also cause erratic operation of the TXV if moisture freezes at the TXV and restricts refrigerant flow. The moisture and acid will cause chemical instability within the system and may cause other system components to malfunction.[16]

As part of the Foreign Military Sales Program, the CFC Elimination Team converted air conditioning and refrigeration plants on FF-1052 Class ships sold to the Taiwanese Navy [17] and on the Spanish frigate CANARIAS, F-86 (a modified FFG-7 design).[18] The Spanish and Taiwanese Navy technicians were trained to continue the conversion of air-conditioning and refrigeration plants for their Navies. The CFC Elimination Team is supporting additional international efforts by furnishing ship alteration records, installation procedures, and lessons learned to the Royal Australian and Hellenic Navies.

In addition to assisting foreign navies, NSWCCD Philadelphia has entered into an agreement with the U.S. Army to convert the air-conditioning and refrigeration systems aboard 101 Army vessels from CFC-12 and CFC-502 to ozone-friendly alternatives.[19] Finally, the CFC Elimination Team is assisting the U.S. Military Sealift Command (MSC) by providing conversion procedures and documentation, and a number of conversion kits and supporting software (including technical manuals, drawings, and parts lists).

Submarine Life Support System Testing:

A submarine's atmosphere under normal conditions should contain only trace amounts of refrigerants. Chemical decomposition products of refrigerants will form while passing through the submarine carbon monoxide and hydrogen (CO/H_2) burner. Due to a submarine's closed environment, those decomposition products must not be harmful. The Navy performed an investigation to determine the CO/H_2 burner temperature which will result in acceptable refrigerant decomposition levels for the alternative refrigerants under consideration. The investigations revealed that HFC-134a and the potential CFC-114 alternative refrigerants HFC-236fa and HCFC-124 required the CO/H_2 burner temperature to be lowered from 600^{o}F to 500^{o}F in order to obtain acceptable refrigerant decomposition levels. Refrigerants E-134 and HFC-236ea, also considered as potential replacements for CFC-114, decomposed excessively even at reduced CO/H_2 burner temperatures, thereby eliminating them from consideration as submarine alternative refrigerants. The Navy is re-qualifying submarine CO/H_2 burners for operation at the reduced temperature, while ensuring that the performance of the burner is not adversely affected and the safety of submarine personnel is maintained. Testing has demonstrated that trace contaminants in submarine atmospheres are not significantly affected by lowering the burner temperature.

The first submarine refrigeration plant conversion to HFC-134a is currently schedule to occur on an SSN-688 Class submarine (USS Boise, SSN-764) during late FY97. Following the conversion, the modified refrigeration plant and the submarine's atmosphere will be thoroughly monitored to ensure satisfactory performance of all systems.

EXISTING CFC-114 AIR-CONDITIONING PLANT CONVERSION PROGRAM

The Navy is one of the largest users of refrigerant CFC-114 in air-conditioning equipment, with over 959 plants installed onboard 252 surface combatant and submarines[20]. These plants produce chilled water for various cooling applications including weapon systems and are considered mission critical equipment. Anticipating the production ban of CFCs on 31 December 1995, the Navy developed a strategy to assure continued operation of these mission critical plants. Since it would be cost prohibitive to replace the existing CFC-114 air-conditioning plants with new ozone-friendly plants, the Navy started to investigate alternative refrigerants to backfit into the CFC-114 air-conditioning plants. In order for a candidate replacement refrigerant to be considered, it must meet various key parameters. Refrigerant physical parameters that must be considered include: boiling point, critical temperature, evaporator pressure, condenser pressure, ozone depletion potential (ODP), global warming potential (GWP), flammability and toxicity. In addition, it is desirable that the performance of a candidate refrigerant in an actual air-conditioning plant replicate the performance of refrigerant CFC-114. The refrigerant flow rate, cycle efficiency, material compatibility, and thermodynamic properties are all factors which must be evaluated. An environmentally-safe alternative replacement refrigerant for CFC-114 was not available at the start of the program thus considerable effort went into identifying a suitable replacement. The Navy has considered four refrigerants as possible replacements: E-134, HCFC-124, HFC-236ea and HFC-236fa. Table 3 compares the critical parameters for each of these refrigerants with CFC-114.

Alternative Refrigerants for CFC-114:

E-134:

Bi-(difluoromethyl)-ether (E)-134 was first favored by the Navy as a replacement refrigerant for CFC-114. E-134 contains no chlorine and therefore has zero ODP. Its preliminary physical properties are very similar to CFC-114 and was considered a near drop-in replacement refrigerant. This refrigerant was dropped from further consideration because of the difficulty and high cost to synthesize. In addition, E-134 was incompatible with common air conditioning plant materials and decomposed readily in submarine life support systems.

HCFC-124:

Hydrochlorofluorocarbon (HCFC)-124 (1-chloro-1,1,2,2,-tetrafluoroethane) contains a chlorine atom and therefore has a small, non-zero, ODP (0.02) The GWP of HCFC-124 is also small (0.07). Its production, however, is controlled by the Montreal Protocol and the U.S. Clean Air Act and is currently scheduled for a complete production ban in 2030. This refrigerant operates at considerably higher pressures than CFC-114 which creates a potential air conditioning plant mechanical stress problem. Existing Navy centrifugal compressors are incompatible with this refrigerant due to significant differences in the refrigerant flow rate and pressure. This would require the development of a family of compressors optimized specifically for refrigerant HCFC-124. Also in August 1994, Chief of Naval Operations (CNO) directed NAVSEA to terminate R&D efforts related to refrigerants with an ozone potential greater than zero, including HCFC-124 [21]. Therefore, refrigerant HCFC-124 was dropped from further considerations.

HFC-236ea:

The EPA proposed this refrigerant as a potential replacement for CFC-114. Hydrofluorocarbon (HFC)-236ea (1,1,1,2,3,3-hexafluoropropane) contains no chlorine and thus has zero ODP. The physical properties of this refrigerant are a closer match to CFC-114 from a pressure and flow rate standpoint than HCFC-124. However, compressor modification would still be required. Testing with submarine atmospheric control system revealed excessive refrigerant decomposition even at lower CO/H_2 burner temperatures. The excessive refrigerant decomposition eliminated this refrigerant from further consideration as a replacement for CFC-114. Initial laboratory investigations with HFC-236ea also revealed that it did not perform as originally predicted in a centrifugal compressor air-conditioning plant.

HFC-236fa:

HFC-236fa, (1,1,1,3,3,3-hexafluoropropane), which is an isomer of HFC-236ea, is another refrigerant considered as a replacement for CFC-114. HFC-236fa contains no chlorine and thus has zero ODP. The physical properties of this refrigerant are also a closer match to CFC-114 from a pressure and flow rate stand point than HCFC-124. A joint Navy/EPA toxicity testing program for HFC-236fa has yielded satisfactory results. The Navy selected HFC-236fa as the backfit refrigerant alternative for CFC-114 plants in early FY 95 due to favorable laboratory testing and toxicity testing results, and production commitments from chemical companies.

Table 3. Comparison Of Alternative Refrigerants To CFC-114.

	CFC-114	HCFC-124	HFC-236fa	HFC-236ea	E-134
Chemical Formula	$C_2Cl_2F_4$	HC_2ClF_4	$CF_3CH_2CF_3$	CF_2CHFCF_2H	$C_2H_2F_4O$
Boiling Point (^oF)	38.60	8.26	29.15	43.70	43.3
Evaporator Pressure (psia)[1]	15.13	27.90	18.76	13.67	13.59
Condenser Pressure (psia)[1]	46.14	80.94	59.15	45.54	47.09
Flow Rate (ft^3/min/ton)[1]	9.31	5.06	7.19	9.22	8.52
Power (kW/ton)[1]	0.59	0.50	0.51	0.50	0.49
Ozone Depletion Potential[2]	0.7	0.02	0	0	0
Global Warming Potential[2]	2.3	0.07	1.7	0.17	-[3]

[1] Assumes 40^{o}F evaporating and 100^{o}F condensing temperatures , and an ideal cycle (100% efficient compressor and motor)

[2] ODP and GWP is reference to refrigerant CFC-11 which has a value of 1.0

[3] Insufficient data available

Alternative Refrigerant Heat Transfer Testing:

A laboratory 125-ton CFC-114 air-conditioning plant test facility at NSWCCD Annapolis was used to analyze the operation and heat transfer characteristics of the various alternative refrigerants. This facility is comprised of a Navy CFC-114 centrifugal compressor with a commercial heat exchanger package configured with the same tube configuration (type and number) used on the shipboard 125-ton air conditioning plants. The HCFC-124 investigation was performed with a CFC-114 impeller design operating at an off-design condition and confirmed the need for new compressors if HCFC-124 was to function optimally in the existing air conditioning plants. HFC-236fa and HFC-236ea were also tested in the facility. The investigations revealed that HFC-236fa performed adequately as a refrigerant while HFC-236ea did not perform as predicted.

NIST Refrigerant Properties:

The thermophysical and thermodynamic properties of a potential alternative refrigerant must be accurately known in order to predict its performance in an air-conditioning plant. Refrigerants with low thermal characteristics or poor cycle efficiency would be dropped from further consideration and efforts concentrated on promising alternatives. While this information was known for the existing commercially available refrigerants, very little information was available concerning many of the alternative refrigerants. The Navy funded National Institute of Standards and Technology (NIST) to measure the thermophysical and thermodynamic properties of the alternative refrigerants. This data was then incorporated into the NIST computer model of refrigerant properties REFPROP version 5.0 [22].

Oil & Compatibility Testing:

Material and lubricant compatibility is also crucial in selecting a potential alternative refrigerant. Both the refrigerant and lubricant must be compatible with each other and materials that are common to the existing compressors and heat exchangers. Materials such as o-rings, gaskets, seals, motor windings, heat exchanger tubes, compressor castings, etc., must be tested for use with the alternative refrigerants. The Navy funded Spauschus Associates to perform material compatibility testing.

Air-Conditioning Plant Stress Analysis:

Many of the alternative replacement refrigerants have higher operating pressures than CFC-114. It is important to determine if these pressures will generate stresses which exceed the air-conditioning plants' design limits. Westinghouse MTD and John J McMullen Associates were tasked to perform a finite element stress analysis for each shipboard CFC-114 air conditioning plant design. Plants with acceptable analysis results will then be hydrostatically tested. Structural modifications will be investigated for plants which have unacceptable analytical results. If modifications are not feasible, these plants will be vintaged for continued operation with CFC-114. The original analyses were performed using refrigerant HCFC-124 pressures. Scaling of those results with the lower pressures of HFC-236fa revealed that all plant designs except one are acceptable, and structural modifications are currently being investigated for that design. Hydrostatic testing will be performed on all laboratory test units and on all shipboard units as they are converted.

Toxicity Testing:

To ensure the safety of Navy personnel, toxicity tests were conducted on HFC-236fa. Since HFC-236fa was not yet a commercialized refrigerant at the beginning of the Navy's investigations, only limited toxicity testing had been performed by industry. The Navy worked closely with the Environmental Protection Agency (EPA) on a program to determine the toxicology characteristics of HFC-236fa. The Navy Medical Research Institute also provided technical support by reviewing protocols, recommending test conditions, and gathering data necessary for the Navy Environmental Health Center to determine allowable exposure limits for shipboard applications. HFC-236fa was approved as an acceptable alternative to CFC-114 in centrifugal plants by the EPA on December 19, 1995.[23]

CONVERSION KIT DEVELOPMENT FOR FLEET CFC-114 AIR-CONDITIONING PLANT DESIGNS

Since it was not known how the existing CFC-114 air-conditioning plants would operate with an alternative refrigerant, it was necessary to qualify conversion kits for each Fleet CFC-114 air-conditioning plant design in the laboratory prior to fleet implementation. Each of the Fleet's major CFC-114 air-conditioning plant designs were procured and installed at NSWCCD Annapolis. The air-conditioning plants that were procured in support of this program included the following ship classes: CG-47, DDG-51, LHD-1, CV SLEP/CVN-68, SSN-688, SSBN-726, DD-963, DDG-993, AOE-6 and LCC-19. A 125-ton air-conditioning plant used on LSD-44 class ships was obtained from the supply system while the prototype 225-ton air-conditioning plant for the SSN-21 class was available to support this program. Although submarine CFC-114 air-conditioning plants were initially procured for laboratory investigations, backfit conversion kits are not being developed for these plants. In August 1994, CNO sponsors established a policy that submarine CFC-114 air-conditioning plants will rely on the Navy's mission critical reserve of CFC-114, and therefore will not undergo conversion [21].

The laboratory qualification of conversion kits requires the simulation of a wide range of air-conditioning plant operating conditions. Three Cooling System Dynamometers (CSD) were constructed at NSWCCD Annapolis in support of this effort. After receipt, the air-conditioning plants were installed in the CSDs and were fully instrumented to allow performance and acoustic measurements. Each of the air-conditioning plants was baselined with CFC-114 to assure proper plant operation prior to modification kit installation.

New compressors will be required during the conversion of CFC-114 air-conditioning plants. The performance of new compressor designs must be measured to assure that operation meets the predicted performance and to develop control algorithms. It is not possible to accurately measure the performance of a compressor while installed on an air-conditioning plant. A unique facility was required that can measure refrigerant flow and compressor head at various operating conditions for a variety of refrigerants.

A Centrifugal Compressor Development Facility (CCDF), Figure 5, was designed and constructed at NSWCCD Annapolis to support this program. Baseline testing of the CCDF with refrigerant CFC-114 was performed with a compressor that had been previously mapped. The compressor performance measured by the CCDF matched results for the same compressor measured in a similar facility at York International during the compressor development for the SSN-21 class air-conditioning plant.

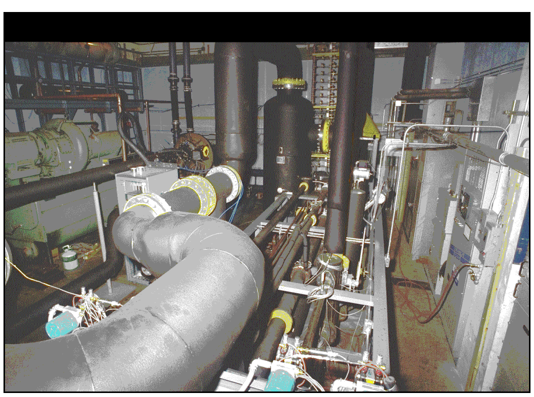

Figure 5. Centrifugal Compressor Development Facility.

Conversion Kit Development Contract:

The Navy awarded a contract to York International Corporation (York) in December 1992 to assist the Navy with engineering services and for prototype conversion kit design and fabrication. Specifically, York was tasked to survey the Fleet's CFC-114 air-conditioning plant population in order to determine current shipboard air-conditioning plant types and quantities, and to ensure that conversion kits will utilize standardized components wherever possible. In addition, York was tasked to perform a compatibility investigation of hermetic motor materials. The purpose was to assure the compatibility of hermetic motor materials with the replacement refrigerant and lubricant. York was also tasked to support the stress analyses of Fleet air-conditioning plants required due to the higher operating pressures of the proposed alternative refrigerants.

York was also tasked to design and fabricate centrifugal compressors for each of the different air-conditioning plant capacities. A total of five different compressor designs are under development including: 125/150, 200, 250, 300, 363-ton compressors. The contract specified fabrication of compressors for each of the laboratory air-conditioning plants at NSWCCD Annapolis plus one of each compressor design for mapping in the CCDF. The new compressors incorporate a variable geometry diffuser (VGD), Figure 6. The VGD optimizes the refrigerant flow path through the compressor which reduces or eliminates the need for hot gas bypass and improves the part load operation and structureborne noise levels. This device is located at the exit of the impeller and moves axially to vary the diffuser gap.

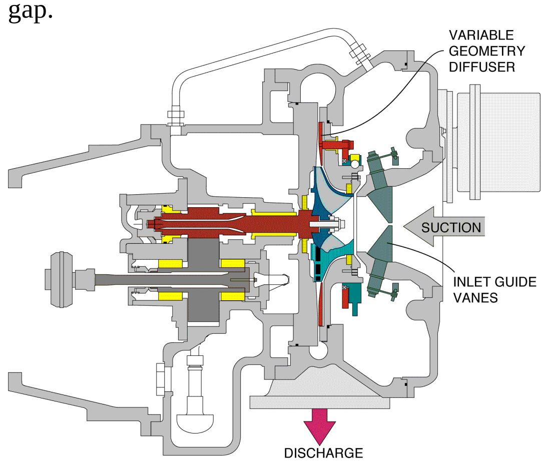

Figure 6. Variable Geometry Diffuser Centrifugal Compressor.

The Navy also tasked York to design and fabricate a universal microprocessor-based control system, Figure 7. This was necessary since the existing CFC-114 air-conditioning plants use pneumatic control systems which have a history of failure. The universal control system will improve reliability, maximize component commonality and minimize development and logistics support costs. It is also required to optimize the operation of the centrifugal compressor variable geometry diffuser (VGD). A universal microprocessor-based control system will be fabricated for each of the Fleet air-conditioning plants installed in the laboratory.

A second engineering services contract was awarded to York International in June 1997. York was tasked to complete conversion kit designs and fabrication of compressors and universal control panels for the laboratory conversions. York will also fabricate two conversion kits for a shipboard installation validation scheduled during May 1998. Future delivery orders will task development of Integrated Logistic Support, Planned Maintenance System, Technical Manuals, installation drawings and related software items.

Shock and vibration qualification of a HFC-236fa CG-47 class air-conditioning plant is also planned for Fall 1997.

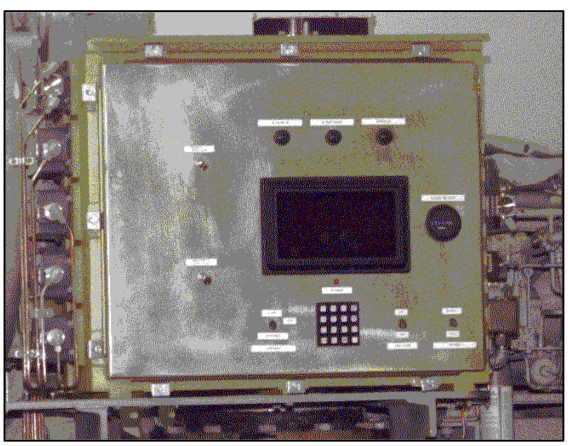

Figure 7. Universal Microprocessor Control System.

Laboratory Qualification:

Proof-of-Concept demonstrations with HFC-236fa in Fleet air-conditioning plants were initiated in FY 1995. The three Fleet plants selected for this demonstration were the CG-47, DDG-51 and LHD-1 class air-conditioning plants. The "proof-of-concept" demonstrations were performed to prove the suitability and effectiveness of the planned modifications to the Fleet CFC-114 air-conditioning plants. The existing plant compressors were removed and a converted CFC-114 compressor was installed with the proper gear code. The plants were operated over their normal operating range at various condenser water inlet temperatures. Plant power and capacity data were measured and compared with the CFC-114 baseline data. Operation of the converted air-conditioning plants with HFC-236fa and a polyol ester (POE) lubricant was performed until the final design HFC-236fa compressors were ready.

The first conversion kits were delivered to NSWCCD Annapolis in FY96. The CG-47 and DDG-51 class kits were installed and qualification investigations are underway, Figure 8. The converted air-conditioning plants have met all critical design requirements including power consumption, part load operation and structureborne noise. Further refinement and qualification of the conversion kits continues. Other kits will be installed for qualification investigations as they are received from York

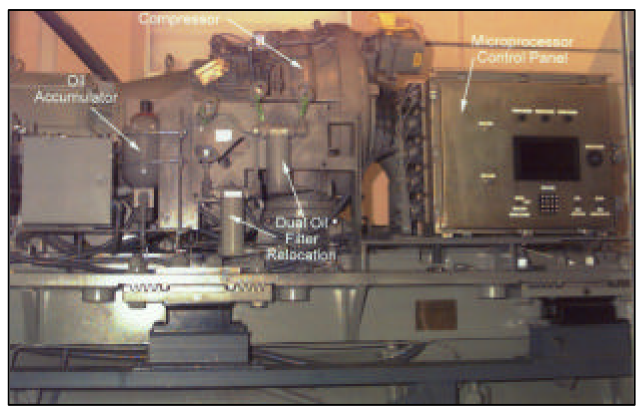

Figure 8. Shipboard-Type 200-Ton CG-47 Class Air-Conditioning Plant Converted for HFC-236fa.

Shipboard Installation Validation:

A shipboard installation validation will be performed on the USS Normandy (CG-60), Figure 9, to validate conversion kit installation and operation. Kits will be installed on two 200-ton CFC-114 air-conditioning plants on board the USS Normandy during a planned overhaul in Norfolk, Virginia starting in May 1998.

Figure 9. USS Normandy (CG-60), Planned First Installation of CFC-114 Conversion Kits .

Procurement And Installation Of Production Kits:

Acquisition Plan 97-004 [24] outlines a strategy for the procurement and installation of 583 conversion kits for surface ship CFC-114 air-conditioning plants. Contracts will be awarded according to the availability of the qualified conversion kit design, availability of ships and funding availability. A total of 7 contracts are planned with the last contract option to be exercised in 2007. The first production kit installations are planned for FY99 onboard CG-47 class ships. Up to 12 conversion kits will be installed during the first year. The conversion rate will increase during each successive year reaching maximum of approximately 70 plants per year.

NEW HFC-134A AIR-CONDITIONING AND REFRIGERATION PLANTS FOR FUTURE SHIPS

The Navy must develop new-design air-conditioning and refrigeration plants which operate using non-CFC refrigerants for new construction ships and future shipboard installations of new equipment. This is necessary to comply with Navy and DoD directives which require that CFC-based equipment may not be used in new installations whenever suitable alternatives exist. New shipboard air-conditioning and refrigeration plant designs will be optimized to use an environmentally acceptable non-CFC refrigerant, and incorporate modern state-of-the-art technology advancements wherever practicable, feasible and cost-effective.

HFC-134a was selected as the non-CFC refrigerant for new-design shipboard air-conditioning and refrigeration equipment, based on its thermodynamic and physical properties, and its widespread use throughout commercial industry. HFC-134a is a fully commercialized refrigerant, and therefore is expected to be readily available at a competitive cost. Since HFC-134a is widely used throughout industry, its characteristics are becoming well-known and there is a vast and growing technical base of information for HFC-134a.

Approach:

The Navy's approach for developing a new family of shipboard HFC-134a air-conditioning and refrigeration plants is as follows:

- HFC-134a twin screw compressor air-conditioning plants are being developed for shipboard applications requiring 125-tons of cooling capacity and less. These are applications where CFC-12 air-conditioning plants have traditionally been used.
- HFC-134a centrifugal compressor air-conditioning plants are being developed for shipboard applications requiring a cooling capacity greater than 125-tons. These are applications where CFC-114 air-conditioning plants have traditionally been used.
- HFC-134a refrigeration plants are being developed for all Navy ship stores applications, where CFC-12 has previously been used. Most of the new plant designs will incorporate rotary refrigeration compressors, which are anticipated to provide reliability, noise and efficiency benefits when compared to the reciprocating compressor designs that are currently used.

The following development efforts are being pursued at NSWCCD Annapolis under the sponsorship of the NAVSEA CFC & Halon Elimination Program:

125-Ton HFC-134a Twin Screw Compressor Air-Conditioning Plant:

A 125-ton HFC-134a twin screw compressor air-conditioning plant for general surface ship applications is being developed under an R&D contract with York International Corporation. A prototype plant, Figure 10, has been designed and fabricated and is currently undergoing manufacturer's qualification testing. The prototype unit produces the design 125-ton cooling capacity with a specific power consumption of 0.65 kilowatts per ton, an improvement of more than 50% over existing CFC-12 reciprocating compressor air conditioning plants. Features of this unit include a high-efficiency twin screw compressor, a high-efficiency sealed insulation system hermetic motor, a microprocessor-based control system, enhanced evaporator tubes, and a titanium condenser.

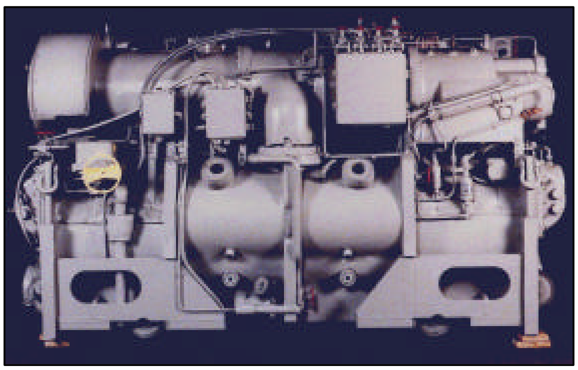

Figure 10. Prototype 125-ton HFC-134a Twin Screw Compressor Air-Conditioning Plant.

The prototype twin screw compressor air-conditioning plant recently passed a vibration test and a floating platform shock test at Hi-Test Laboratories, Arvonia VA. All other qualification testing, including a maintainability demonstration and Electromagnetic Interference (EMI) testing, is scheduled for completion later in 1997.

The United Kingdom's Ministry of Defense is benefiting from this R&D effort, as a fresh-water-cooled 128-ton version of the HFC-134a twin screw compressor air-conditioning plant will be installed onboard their Trafalgar Class of submarines. These plants will be used to replace CFC-12 reciprocating compressor air-conditioning plants.

200-Ton HFC-134a Centrifugal Compressor Air-Conditioning Plant:

The majority of Navy shipboard centrifugal compressor air-conditioning plant applications are in the 150 to 250-ton cooling capacity range. A 200-ton HFC-134a centrifugal compressor air-conditioning plant for surface ship applications is also being developed under an R&D contract with York International Corporation. This plant will serve as the baseline design for future surface ship HFC-134a centrifugal compressor air-conditioning plants.

The 200-ton HFC-134a plant has been designed and fabricated, and is currently undergoing qualification testing at York International Corporation. The prototype plant, Figure 11, incorporates a new-design, high speed centrifugal compressor designed specifically for HFC-134a. The compressor has a new aerodynamic design impeller, and a Variable Geometry Diffuser (VGD) feature which improves off-design efficiencies and acoustic levels by optimizing the refrigerant flow path leaving the impeller. Other design features include a microprocessor-based control system which will be used to control the compressor VGD and capacity control mechanisms, high flux nucleate boiling surface evaporator tubes and a titanium condenser.

The prototype 200-ton HFC-134a plant was also successfully shock and vibration tested. The high-impact barge shock test of the 200-ton air conditioning plant is shown in Figure 12. Manufacturer's qualification testing will be completed later in 1997. The 200-ton HFC-134a plant design is currently planned for installation on DDG-51 Flight IIA ships, starting with DDG-83, with four plants per ship. LPD-17 Class ships will also receive the 200-ton HFC-134a plant design, with seven plants per ship.

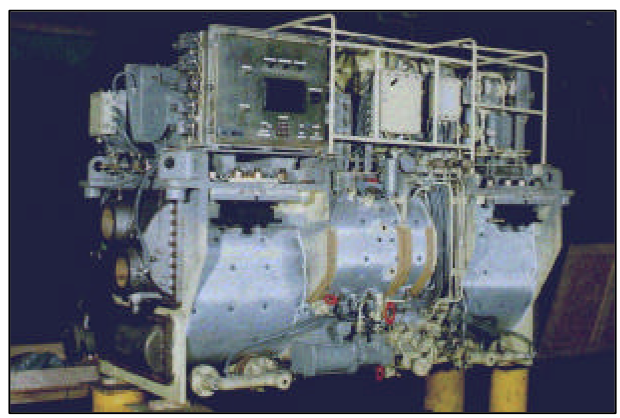

Figure 11. Prototype 200-ton HFC-134a Centrifugal Compressor Air-Conditioning Plant.

Figure 12. High-Impact Shock-Qualification Test Of 200-ton HFC-134a Centrifugal Compressor Air-Conditioning Plant (In Barge).

1.5-Ton HFC-134a Rotary Compressor Refrigeration Plant:

A 1.5-ton cooling capacity HFC-134a ship stores refrigeration plant is also being developed for surface ship applications. The prototype plant, Figure 13, has been designed, fabricated and is currently undergoing manufacturer's qualification testing at York International Corporation. The plant incorporates a rotary vane compressor design, and will be the Navy-standard HFC-134a ship stores refrigeration plant design. This plant is also planned for installation on DDG-51 Flight IIA ships, starting with DDG-79, and LPD-17 Class ships.

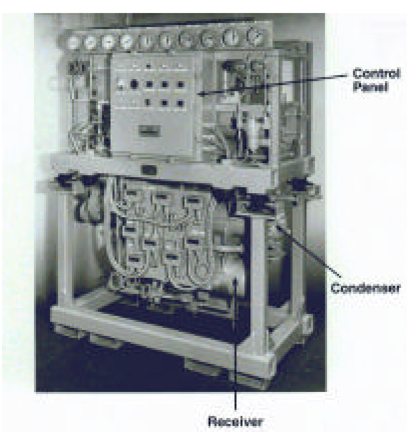

Figure 13. Prototype 1.5-ton HFC-134a Rotary Compressor Refrigeration Plant.

Other Designs:

Other U.S. Navy shipbuilding programs are also developing HFC-134a air-conditioning and refrigeration plants for new construction applications. The CVN-76 aircraft carrier program is developing a new 800-ton HFC-134a centrifugal compressor air-conditioning plant design, which incorporates many of the same design features as the 200-ton HFC-134a centrifugal air-conditioning plant. Six 800-ton HFC-134a plants will be installed on CVN-76, and possibly on CVN-77.

The New SSN submarine program is also developing a new, fresh-water-cooled 450-ton HFC-134a centrifugal compressor air-conditioning plant, and a 1.0-ton HFC-134a ship stores refrigeration plant for the next generation of Navy attack submarines.

Alternative Cooling Technologies:

A small R&D effort exists to investigate alternative non-vapor compression cooling technologies that do not rely on conventional halocarbon refrigerants such as HFC's and CFC's. Latent concerns over the Global Warming Potential (GWP) of halocarbon refrigerants make the non-vapor compression cooling design concept attractive, however at this stage of development most alternative cooling technologies are not competitive from an energy efficiency standpoint. The increased energy consumption of alternative cooling systems would have a negative impact on global warming, as more electrical power generation (and fossil fuel consumption) would be required to enable operation of these systems. Most alternative cooling technologies will not be mature until well into the next century, and there is very limited R&D funding available to pursue these technologies.

Currently, thermoelectric cooling is the only alternative technology area being investigated under the NAVSEA CFC & Halon Elimination Program. Thermoelectric devices operate silently, have no moving parts, provide both heating and cooling, and can be easily configured to meet specific requirements. The overriding disadvantages of thermoelectric cooling at this time are poor energy efficiency and high acquisition costs when compared with vapor compression systems. Current efforts are focused on developing improved thermoelectric materials to increase energy efficiency. Significant breakthroughs in improved thermoelectric materials are required prior to further investigations into prototype hardware for shipboard applications.

GALLEY-TYPE REFRIGERATION EQUIPMENT

The majority of galley-type refrigeration equipment uses CFC-12 and, to a much lesser extent, R-502 (composed of hydrochlorofluorocarbon (HCFC) -22 and CFC-115) as a refrigerant. Equipment that falls under this category includes water fountains, beverage dispensers, salad bars, ice-cream machines, *et cetera*.[25] This type of equipment is not centrally controlled by the Navy and, subsequently, ships operate a wide variety of mostly undocumented equipment numbering 10,000 or more in population. Due to these conditions, a centrally-planned and centrally-managed conversion or replacement program is a very difficult proposition. Nevertheless, this equipment is important for the quality of life of shipboard personnel and the increasing difficulty in obtaining refrigerant from commercial markets to support this equipment threatens that quality of life.

Although this type of equipment is not considered to be "mission-critical", the Chief of Naval Operations is allowing interim support from the Navy's reserve at least until the end of 2002.[26] Fortunately, these systems have non-negligible natural attrition rates and galley-type refrigeration equipment is slowly but surely being replaced by equipment that uses ozone-friendly, commercially-available refrigerants such as HFC-134a.[27] The Navy is now monitoring the Fleet's galley-type refrigeration equipment to see whether those attrition rates will be sufficient to eliminate this problem by the end of 2002. If natural attrition rates are sufficient, the Navy will be able to avoid the need of conversions or costly system replacements.[28]

With respect to new-ship construction, industry now provides galley-type refrigeration equipment of all types that uses alternative refrigerants.

HALON FIRE-FIGHTING SYSTEMS

Existing Systems:

In 1989, the Navy adopted sulfur hexafluoride (SF_6) to replace Halon 1301 for testing shipboard fire-fighting systems. This action eliminated over sixty percent of the Navy's atmospheric emissions of Halon 1301 and contributed greatly to the Navy's overall conservation policy. Unfortunately, SF_6 is not an acceptable fire-fighting agent and, therefore, cannot be used as a retrofit candidate for Halon 1301 systems.[6]

Unlike progress made with refrigerants, drop-in or near-drop-in substitutes for Halons that meet Navy requirements have yet to be identified. The closest alternative identified to date for Halon 1301, CF_3I, provides similar fire-fighting characteristics. However, its toxicity makes it inappropriate for shipboard applications. Other alternatives, such as heptafluoropropane, also known as HFP of HFC-227ea, require two to three times the space and weight for the same fire-fighting capability and, therefore, are not necessarily practical for incorporation into existing ships.[29] Due to the lack of a feasible alternative, the Navy will support existing shipboard Halon 1301 fire-fighting systems from the Navy's reserve until those ships retire. For similar reasons, mission-critical shipboard fire-fighting systems employing Halon 1211 will be supported by the Navy's reserve until those systems are retired.[8]

Future Systems:

For new ship construction, research and development efforts have examined a broad range of fire-fighting technologies. One such technology is fine-aerosol generation whereby a solid propellant is burned and a fine, fire-fighting aerosol is released. Fine-aerosol generators have many benefits over Halon-like agents including weight and space savings for the same fire-fighting capability. However, there are also a number of challenges associated with this technology including managing the high temperature of the burning propellant and the non-clean-agent residue that can be both toxic to humans and corrosive to shipboard systems.[30]

HFP is one of a number of clean, commercially-available, ozone-friendly, Halon-like, gaseous, fire-fighting agents that have been evaluated for shipboard use. In fact, HFP has been selected for use aboard LPD 17 in non-machinery spaces that would normally be protected by Halon 1301 or CO_2.[31] As stated previously, HFP requires two to three times the space and weight of Halon 1301 for the same fire-fighting capability. However, these additional space and weight requirements can be taken into consideration for new ship design.

Fine-Water Mist is another fire-fighting technology that can suppress fires and significantly reduce the temperature of a compartment, thus greatly facilitating the work of damage-control teams. Since the agent is water, there is no ozone-layer or global-warming impact resulting from an atmospheric release and there is no threat of environmental regulation. The LPD 17 will take advantage of these benefits and use Fine-Water Mist in machinery spaces.[31]

SOLVENTS AND OXYGEN-SYSTEM CLEANING

For the most part, the Navy's solvent requirements are not significantly different from those of private industry. Not too many years ago, the Navy was heavily dependent on methyl chloroform, carbon tetrachloride, trichlorotrifluoroethane (CFC-11), trifluoroethane (CFC-113), and other ODS solvents for a number of cleaning applications. For obvious reasons, private industry was equally or more so affected by the production cessation of ODS solvents and, therefore, undertook to identify suitable alternatives for processes such as degreasing, electronics cleaning, and precision cleaning. Where appropriate, alternatives that were identified by private industry have been adopted by the Navy. Subsequently, the majority of the Navy's ODS solvent applications have since been switched to alternative chemicals and processes.

One notable exception, however, is the use of CFC-113 in the cleaning of oxygen systems. Critical oxygen systems include oxygen piping systems aboard surface ships and submarines, components of diving systems, and welding equipment. Relatively small amounts of contamination in these systems, such as what might be found after incomplete cleaning, can result in auto-ignition and serious injury since metals such as steel and aluminum burn very rapidly in an environment of pure oxygen. In addition, diving systems provide an additional challenge since the toxicological effects on humans of any residue left in the system are significantly magnified at the higher pressures associated with diving.

With no suitable alternative available from industry, the Navy worked with the private sector to develop a new product now known as the Navy Oxygen Cleaner (NOC). NOC is an aqueous, inorganic, alkaline solution with zero ozone-depleting potential, zero global-warming potential, is not a Volatile-Organic Compound, and is now used for 95% of the Navy's ship-related oxygen cleaning (except for cleaning oxygen gages, instruments, and other limited applications). In fact, NOC is so environmentally benign that many municipalities allow NOC to be disposed of in sewer systems with minimal treatment. As a result NOC has allowed the Naval Sea Systems Command to reduce its annual use of CFC-113 by approximately one-million pounds.[32]

NOC is being used to clean oxygen systems aboard submarines and surface-ship, in commercial and military diving equipment, and on commercial and military aircraft. NOC is proving to have wide-spread applications in the aerospace, diving & marine industry, and many other commercial and military sectors in this country and around the world. NOC, which is the subject of two patents held jointly by the Navy and industry [33,34], is making the transition away from CFC-113 easy while providing environmental and safety benefits.

In addition, cost avoidance and royalties paid to the U.S. Government associated with NOC and related patents are estimated to be $12 million annually thus demonstrating that environmental protection can have substantial economic benefits.[35]

FUTURE CONSIDERATIONS

At this time, the only proposed modifications to the Montreal Protocol and subsequent treaties that might affect shipboard systems are (1) a proposal to accelerate the production cessation of hydrochlorofluorocarbons (HCFCs) and (2) a proposal to ban the use of Halon. With respect to HCFCs, the Navy operates relatively few shipboard systems that use HCFC refrigerants. Therefore, should an acceleration in production cessation ever be agreed to, a possible strategy by the Navy could be to establish a modest reserve that would support those few systems until retirement. A ban on the use of Halon that did not include a military exemption, however, could have serious consequences since the Navy would be forced to implement costly conversions on existing ships with significant impacts on weight and space. In either case, it should be noted that the U.S. and other parties strongly oppose these proposals and there is no indication at this time that these proposals will be adopted.

Global warming is yet another consideration since many of the ODS alternatives being implemented by the Navy and private industry, such as HFC refrigerants and fire-fighting agents (not to mention the CFCs and Halons that continue to be used in existing systems), are global-warming or greenhouse agents. Ozone depletion not only caused production cessation but also resulted in regulations addressing the handling of material not addressed in this paper. Any international agreements addressing global warming will likely reinforce, strengthen, or even expand these regulations and perhaps introduce production restrictions on the ODS alternatives the Navy now relies upon. Therefore, the United Nations Framework Convention on Climate that is scheduled to take place in Kyoto, Japan, in December 1997, where the Parties could adopt a binding agreement on the emission of greenhouse gases, is being watched very closely.[36]

CONCLUSION

As evidenced by the Fleet-wide conversion programs, the assistance provided to the Army and foreign navies, and the development of new, ozone-friendly products and systems for use by both the military and private industry, the U.S. Navy has taken a leadership role in the transition away from ozone-depleting substances. In fact, the systems and equipment being developed by the program are contributing significantly to one of the Navy's more noteworthy environmental achievements, the amphibious ship LPD-17, which will be the Navy's first "ozone-friendly" ship of the 21st century (Figure 14). In addition to the long list of Navy accomplishments presented in this paper are numerous EPA awards received by individuals and organizations working under the auspices of the CFC & Halon Elimination Program. Therefore, by working cooperatively with industry, other Department of Defense components, and EPA regulators, the potentially serious threat of ODS production cessation has been transformed into success for both the Navy and the environment.

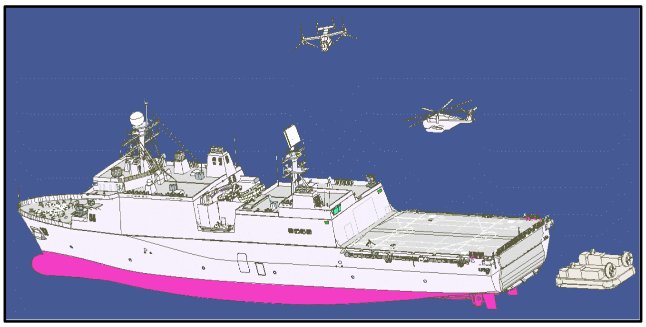

Figure 14. Artist's Conception of the LPD-17: The Navy's First Ozone-Friendly Ship of the 21st Century

ACKNOWLEDGMENTS

The authors wish to warmly thank the many members of the NAVSEA CFC & Halon Elimination Team who made the successes outlined in this paper a reality, as well as the employees of Carrier Corporation, Desmatics, Inc., DuPont, Environmental Protection Agency, Fleet Technical Support Centers, Geo-Centers, Inc., M. Rosenblatt & Sons, Inc., Naval Research Laboratory, Naval Surface Warfare Center Carderock Division, and York International Corporation, with special mention to Neil Antin, Vince Cancila, Vince DiFilippo, Richard Helmick, Dr. Mike Klinkhammer, Joel Krinsky, Peter Mullenhard, Anthony Nickens, Dr. Ron Sheinson, and Bruce Unkel.

REFERENCES

[1] The Montreal Protocol on Substances That Deplete the Ozone Layer, 1987.

[2] "Protection of Stratospheric Ozone; Final Rule", 40 CFR Part 82, July 30, 1992.

[3] "Elimination of Use of Class I Ozone-Depleting Substances in Certain Military Procurement Contracts", Section 326, Department of Defense Authorization Act, 1993.

[4] "Management of Ozone Depleting Substances", Chief of Naval Operations Instruction 5090.1B, Chapter 6, November 1, 1994.

[5] "Operational Requirements Document for LX Amphibious Assault Ship (U)", December 13, 1991.

[6] Krinsky, Joel L., and William Noel, "The Navy's Chlorofluorocarbon/Halon Program", Naval Engineers Journal, May 1991.

[7] "Operational Plan For The Ozone Depleting Substance Reserve", Defense Logistics Agency, June 1997.

[8] "Mission-Critical Reserve of Halons and CFCs", NAVSEA 9510 Serial 03V2/156, July 21, 1994.

[9] "Department of the Navy ODS Reserve Monitoring Plan", NAVSEA 5090 OPR 03V24 Serial 03V2/096, May 9, 1996.

[10] "Navy ODS Reserve Tracking Report", NAVSEA 5090 Serial 03L1/225, May 15, 1997.

[11] "Ozone-Depleting Substance (ODS) Data Call", NAVSEA 5090 Serial 03L1/123, March 11, 1997.

[12] Krinsky, Joel, and Anthony D. Nickens, "U.S. Navy's Ozone Depleting Substance Elimination Program", Conference Proceedings, The 1993 International CFC & Halon Alternatives Conference, 1993.

[13] Hamilton, Donald L., Jr., "Elimination of CFC-12 from Shipboard Reciprocating Compressor Air Conditioning Plants," Carderock Division Naval Surface Warfare Center Report CARDIVNSWC-TR-82-94/35, June 1995.

[14] Wright, K. and V.L. DiFilippo, "Navy Refrigeration Plant Alternative Refrigerant HFC-134a Technical Evaluation Final Report," Carderock Division Naval Surface Warfare Center Report RCS 9516-1, CDNSWC Project D-3043, 23 September 1993.

[15] Wright, Kenneth, "Testing of Carrier Corporation Compressor in HFC-134a Navy Refrigeration Plant," CDNSWC ltr 9516 Serial 9213/326, 27 January 1994.

[16] "HFC-134a Refrigeration System", Naval Surface Warfare Center Ship System Engineering Station, 301930Z, August 1995.

[17] "Navy Converts Taiwan's Ships to Save Ozone", CFC & Halon News, June 1995.

[18] "Navy Helps Spanish Convert Shipboard AC&R", CFC & Halon News, September 1996.

[19] "Army and Navy Team Up to Beat CFCs", CFC & Halon News, Spring 1997.

[20] Air Conditioning and Refrigeration Plants Data Base, March 1997.

[21] "CNO Policy on CFC-114 in Navy Ships and Submarines", CNO 4000 Serial N451F/4U587313, August 8, 1994.

[22] Huber, Marcia, *et alia*, "NIST Thermodynamic Properties of Refrigerants and Refrigerant Mixtures Database (REFPROD)", Version 5.0, February, 1996.
[23] Federal Register, Volume 61 #27, EPA SNAP Notice 4, February 8, 1996.
[24] "CFC-114 AC Plant Conversion", Acquisition Plan # 97-004, May 9, 1997.
[25] Kelly, MM1(SW) Edward D., and Len Derleth, "Galley Refrigeration Systems: Alternative Refrigerant Conversion", Fleet Technical Support Center Porthole, April 1997.
[26] "ODS Material Support for Shipboard, Non-Mission Critical, Auxiliary Refrigeration Equipment", Chief of Naval Operations (N45) 091955Z, October 1996.
[27] "Shipboard Food-Service Equipment Catalog", NAVSEA S6161-Q5-CAT-010.
[28] "Secondary Refrigeration Equipment Replacement", NAVSEA 5090 Serial 03L1/200, December 19, 1996.
[29] Tapscott, Robert E., "Update on Total Flood Options", Conference Proceedings, International Conference on Ozone Protection Technologies, October 1996.
[30] Sheinson, R.S., *et alia,* "Fire Extinguishment by Fine Aerosol Generation", CFC & Halon Alternatives Conference, 1993.
[31] "LPD-17 Shipbuilding Program: A Case Study", CFC & Halon News, June 1996.
[32] Antin, Neil, "NAVSEA Elimination of Ozone Depleting Solvents from the Manufacture and Maintenance of Oxygen Systems." Proceedings, International Conference on Ozone Protection Technologies, October 1996.
[33] Antin *et alia*, "Environmentally Safe, Ready-to-Use, Non-Toxic, Non-Flammable, Inorganic, Aqueous Cleaning Composition", U.S. Patent 5,427,709, June 27, 1995.
[34] Antin *et alia*, "Method of Making an Environmentally Safe, Ready-to-Use, Non-Toxic, Non-Flammable, Inorganic, Aqueous Cleaning Composition", U.S. Patent 5,520,837, May 28, 1996.
[35] Breslin, David, "Use And Value Analysis of the Navy Oxygen Cleaner (NOC)", Naval Sea Systems Command, August 27, 1996.
[36] "Establishment of a Technical Advisory Group on Global Climate Change Issues", CNO 5090 Serial N451I/7U595924, July 1, 1997.